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ELECTRICAL TRANSPORT PROPERTIES OF THE TERNARY COMPOUNDS UTSn, UTSb AND ThTSn

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The resistivity of the equiatomic ternary compounds UTSn, UTSb and ThTSn is up to two orders of magnitude larger than Mooij's criterion: $\rho_{max} = 250$ μΩcm. An exponential decrease of the resistivity at high temperatures suggest a band-gap in spite of the relatively high values for the linear specific heat coefficient γ.

We have prepared a series of the equiatomic ternary compounds UTSn and UTSb, with T a transition metal, in order to gain more insight in the complicated and ambivalent character of the 5f-electrons. In some of these compounds an extremely high resistivity was observed, up to two orders of magnitude greater than the Mooij's criterion of $\rho_{max} = 250$ μΩcm. Additionally we prepared several Th-based compounds ThTSn to serve as non-magnetic reference materials. In these compounds we also found an extremely high resistivity. Although we are unable to provide a complete theoretical description, we present here our experimental findings and discuss these in terms of several models.

The samples were prepared by arc melting appropriate amounts of the constituent elements of at least 99.9% purity under purified argon gas. After arc melting, the samples were wrapped in Ta foil and vacuum annealed at 800°C for at least two weeks. The samples were then characterized by X-ray diffraction which yielded the crystal structure and the lattice parameter [1].

The resistivity was measured by means of a standard four point-probe technique, with a dc current of 5 mA. The samples were spark cut into bars with typical dimensions of $1 \times 1 \times 10$ mm^3. The absolute value of the resistivity was determined at room temperature to be better than 3%, by measuring the voltage drop over the length of a sample with one fixed and one movable potential lead, mounted on a micrometer. This method eliminates possible effects due to inhomogenities or cracks in a sample. The specific heat was measured with an adiabatic heat pulse method using a bare element glass–carbon thermometer mounted on a thin saphire substrate. The heater was evaporated on the substrate and the sample (typically 1 g) was mounted with apiezon-N grease.

The resistivity of the U-based compounds is shown in fig. 1. The values at 4.2 K vary from 170 μΩcm for UCoSn up to 72000 μΩcm for URhSb. The compounds with the highest resistivity show a pronounced maxi-

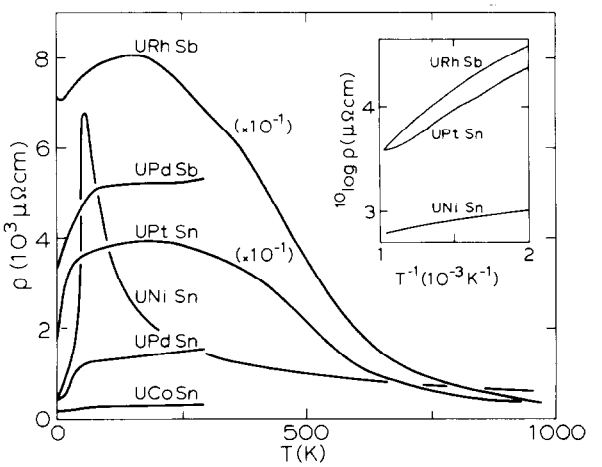

Fig. 1. Temperature dependence of the electrical resistivity ρ for the U-based compounds. The inset shows log ρ vs. T^{-1} between 500 and 1000 K.

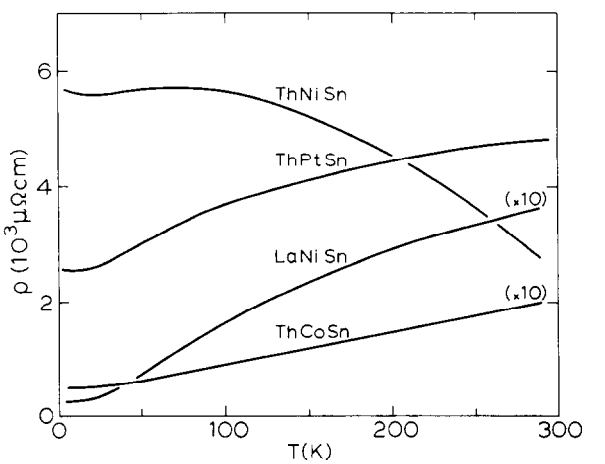

Fig. 2. Temperature dependence of the electrical resistivity ρ for the Th-based compounds and LaNiSn.

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Table 1
Crystal structure, nearest neighbor actinide separation d, magnetic ordering temperature T_c, Curie–Weiss temperature Θ_{CW}, effective moment μ_{eff}, resistivity ρ at 4.2 and 300 K, linear specific heat coefficient γ, and Debye temperature Θ_D

	Struct. type	d (nm)	T_c (K)	Θ_{CW} (K)	μ_{eff} (μ_B/f.u.)	$\rho_{4.2K}$ ($\mu\Omega$cm)	ρ_{300K} ($\mu\Omega$cm)	γ (mJ/mol fu. K^2)	Θ_{Debye} (K)
UPdSb	$CaIn_2$	0.361	65.	+70.	2.92	3500	5300	62.	179.
UPdSn	$CaIn_2$	0.365	29.	−10.	3.16	430	1500	4.3	
UCoSn	Fe_2P	0.372	85.	+25.	3.0	170	300	52.8	194.
UNiSn	MgAgAs	0.451	47.	−75.	3.08	400	1325	28.1	215.
URhSb	MgAgAs	0.462	40.	−111.	3.25	72000	68000	2.1	214.
UPtSn	MgAgAs	0.468	75.	−100.	3.55	19000	36000	10.9	185.
ThCoSn	Fe_2P	0.384	43.	−160.	1.17	47	200	3.7	213.
ThNiSn	MgAgAs	0.463	–	–	–	5700	2770	1.5	228.
ThPtSn	MgAgAs	0.477	–	–	–	2600	4800	2.	–
LaNiSn	ε-TiNiSi		–	–	–	25	361	11.9	198.

mum in the resistivity, beyond which an exponential decrease is observed. Fitting the high temperature data with the formula appropriate for semiconductors, $\rho \sim \exp(-E_g/2k_BT)$, yields $E_g = 0.44$ eV for URhSb, 0.34 eV for UPtSn and 0.12 eV for UNiSn (see inset fig. 1). In fig. 2 we show the resistivity of the Th-based compounds. Here the values at 4.2 K vary from 47 $\mu\Omega$cm for ThCoSn up to 5700 $\mu\Omega$cm for ThNiSn. We list in table 1 some important parameters concerning the structure, magnetism, electrical transport and specific heat. Table 1 indicates that the interactinide separation is larger than the Hill-limit (3.6 Å) and a magnetic moment for U was found accordingly [1].

In the Sommerfield theory of metals a resistivity of 80000 $\mu\Omega$cm leads to a mean free path of about 10^{-2} Å, or a collision rate of about 100 times per interatomic distance. These values are quite unphysical, unless an extreme form of the Kondo state binds all the conduction electrons to the magnetic atoms. However, since the high resistivity is also observed in the Th-based compounds, this possibility is excluded.

Neither the occurrence of heavy fermions ($m^* \gg 1$) can explain the observed phenomena. Although s–f hybridization can cause a steep increase of the resistivity at low temperature, all heavy fermion systems have a resistivity less than the Mooij's criterion at any temperature [2].'

The exponential decrease of the resistivity at high temperature suggests the occurrence of an energy gap in the band structure around the Fermi energy. The cubic MgAgAs-type structure has been shown favourable for the behavior of half metallic ferromagnetism, where an energy gap appears in the band structure of the minority spins [3]. The minority spins are thus semiconducting whereas the majority spins are metallic. As ferromagnetism was only found in UCoSn and UPdSb, all other compounds have no exchange splitted band. This, in our case, could lead to a semiconducting behavior for all electrons, resulting in a resistivity much larger than the Mooij's criterion, and also to the observed exponential behavior of the resistivity at high temperature. The deviations from the exponential behavior at lower temperatures can either be ascribed to impurity states or, more likely, to a temperature dependence of the energy gap, probably induced by magnetic ordering.

This suggestion is opposed by the non-zero values of the linear term of the specific heat γ, usually proportional to the density of states at the Fermi surface. For the above compounds we found values for γ comparable to normal metals, in spite of the observed high resistivities at low temperature. However, it has been shown in the heavy fermion systems that the effective mass of the conduction electrons can be greatly enhanced by s–f hybridization, leading to a corresponding increase of γ [2]. A similar argument would now imply an enhancement of the effective mass of the electrons of the conduction band, and/or holes in the valence band, by supposing that the valence band is dominated by a narrow band of 5f electrons. This leads to an extreme enhancement of γ, with respect to the value expected from the bare density of states at the Fermi surface.

Clearly this picture of enhanced-γ semiconductors is speculative and we urgently suggest band structure calculations for this intriguing class of U-compounds.

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